STH-MDCS/-C Stereo Head
User's Manual

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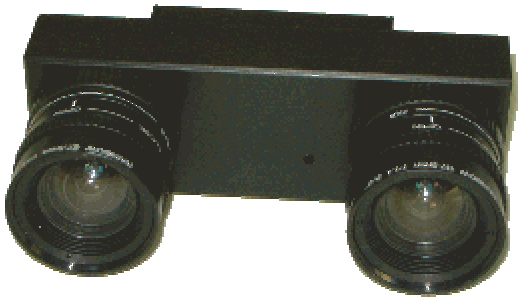

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1 Introduction

The STH-MDCS is a compact, low-power digital stereo head with an IEEE 1394 digital interface. It consists of two 1.3 megapixel, progressive scan CMOS imagers mounted in a rigid body, and a 1394 peripheral interface module, joined in an integral unit.

The CMOS imagers are ½" format, with a resolution of 1280 H by 1024 V pixels, and come in either monochrome (STH-MDCS) or colorized (STH-MDCS-C) versions. These imagers have excellent dynamic range, sensitivity, anti-blooming, and noise characteristics. They are fully controllable via the 1394 interface: the user can set exposure, gain, decimation, etc. They can be used interchangeably with the same interface module.

The STH-MDCS/-C uses standard C-mount lenses for user-changeable optics. Wide-angle to telephoto options are available, depending on the application.

The variable baseline version of the STH-MDCS/-C uses the same imagers, but has a separate IEEE 1394 interface for each imager. It has similar characteristics to the STH-MDCS/-C; please see the STH-MDCS-VAR/-C manual for more information.

There are software drivers for the STH-MDCS/-C for MS Windows 98SE/ME/2000/XP, and for Linux 2.4.x kernels.

SRI's Small Vision System (SVS) software has an interface to the STH-MDCS/-C, and is included with each stereo head. You can simply and automatically calibrate the stereo head, perform stereo correlation, and view the results as a 3D set. The SVS software includes all of the capture software described in this document.

2 Quick Start

The STH-MDCS/-C comes assembled, the interface module mounted to the imager module. The module comes with lenses dismounted.

To set up and test the STH-MDCS/-C, you will need the following:

1. Pair of C-mount lenses, for 1/2" or larger imager (included with the STH-MDCS/-C kit).
2. Host computer with a 1394 PCI or PCMCIA card, OHCI compliant.
3. 1394 6-pin cable.
4. Capture software or Small Vision System installed on the host computer.

Install the 1394 host card, if necessary, according to the directions in Section 7.1. Install the Small Vision System software (see Section 7.2). This is the not-so-quick part of the Quick Start.

Screw the lenses into the mounting holes on the stereo head. Be careful not to force them initially, as you can cross-thread the lens mount. Snug them down, but do not tighten excessively.

Plug one end of the 1394 6-pin video cable into the 1394 jack on the back of the STH-MDCS/-C, and the other into a 1394 port on the host PC. Note: for PCMCIA cards, and laptops with a 4-pin Sony iLink port, an external power supply and adapter are necessary to convert to a 6-pin (signal + power) 1394 plug. Most PCMCIA cards come with this adapter.

Start the SVS main program, `smallv(.exe)` or `smallvcal(.exe)`, on the host computer. You should see a screen as in Figure 2-1. The message window should indicate that the STH-MDCS interface is present. If not, go back to software installation (Section 7.2), and follow the instructions for configuring the correct capture library.

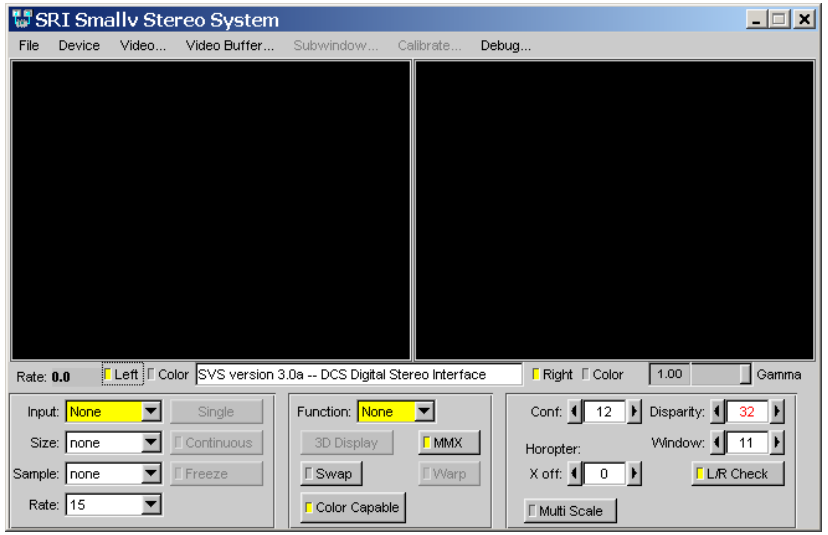


Figure 2-1 SVS main program window.

Pull down the Input chooser, and select the `Video` option. If everything has been set up, the driver software will recognize and configure the stereo head, and a success message will appear in the info text window. If not, the Input chooser will go back to None, and an error message will appear in the info window. Please see Section 7 for troubleshooting.

To view stereo video, press the Continuous button. Left and right images should appear in the application windows. If the message "Image timed out" appears, then there is a problem with the IEEE 1394 drivers; please see Section 7. If the images are too light or too dark, you can open the manual iris of the cameras, or change the exposure and gain settings (Section 6.3). Images can be saved using the File menu.

A more complete description of the video capture program is in Section 6. The SVS programs are described in the documentation that comes with that

software. It is helpful to review Section 6 in conjunction with the SVS documentation.

3 Hardware Overview

Figure 3-1 shows the hardware configuration of the STH-MDCS/-C.

The imager module has a milled Delrin frame that rigidly holds two megapixel imagers, separated by a fixed distance of 9 cm. Lens mounts are an integral part of the frame, and standard C-mount lenses are screwed into these holders. There is an IR cutoff filter, with a knee at approximately 680 nm, permanently mounted inside the lens holder. See Section 4 for appropriate lens characteristics.

The interface module is mounted on the back of the stereo head. One 1394 port is placed at the back of the module; it is inset so that the 1394 plug does not stick out from the device.

A status LED indicates video imager activity. It will turn on when the device is powered and connected to an IEEE 1394 card on the host computer. The LED will begin flashing as soon as images are being acquired by the host computer, at ½ the frame rate. Changing the video modes (frame size, decimation) will cause the frame rate to change, and this will be reflected in the LED flash rate.

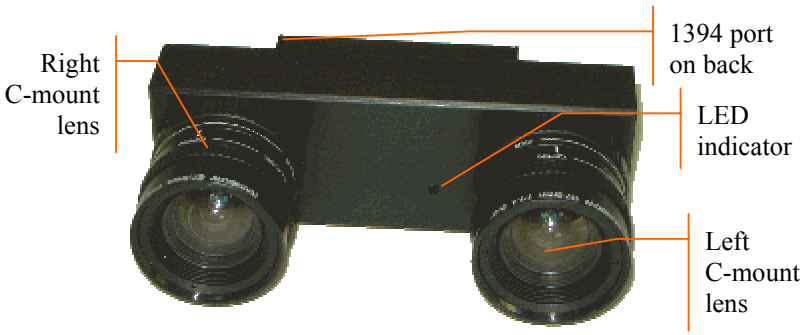


Figure 3-1. Physical layout of the STH-MDCS/-C stereo head.

There are no user-settable switches on the STH-MDCS/-C.

3.1 Hardware Schematic

Figure 3-2 shows the design of the internal hardware of the STH-MDCS/-C. In the stereo imager module, two CMOS imagers, each of size 1280 x 1024 pixels, digitize incoming light into a digital stream. The imagers operate in progressive mode only, that is, each line is output in succession from the full frame.

The maximum video rate is 12 megapixels per second from each imager. The imagers are synchronized to a common clock, so that the corresponding pixels from each imager are output at precisely the same time. Special interlace electronics convert the individual streams into a single pixel-interlaced stream at 24 MHz. The interlaced stream contains one byte from the left imager, then the corresponding byte from the right imager, then the next byte from the right imager, and so on.

The interlaced video stream is transferred to the 1394 interface module, which communicates to the host PC over a 1394 digital cable. The module also accepts commands from the host PC over the cable, and uses these commands to control imaging modes such as exposure or subwindowing.

The 1394 interface module can communicate at the maximum 1394 data rate, 400 MBps.

3.2 Frame Formats and Rates

The 1394 interface electronics supports a maximum rate of 24 megapixels per second. At this rate, there is no need for large buffer memories to hold video data on the stereo device. The STH-MDCS/-C conforms to the IIDC version 1.30 camera specification. Frame rates and frame sizes are set by this standard. The STH-MDS/-C implements the formats shown in Table 1.

The Digital Camera Specification was set up with monocular cameras in mind. To conform to this specification, the STH-MDS/-C uses the YUV

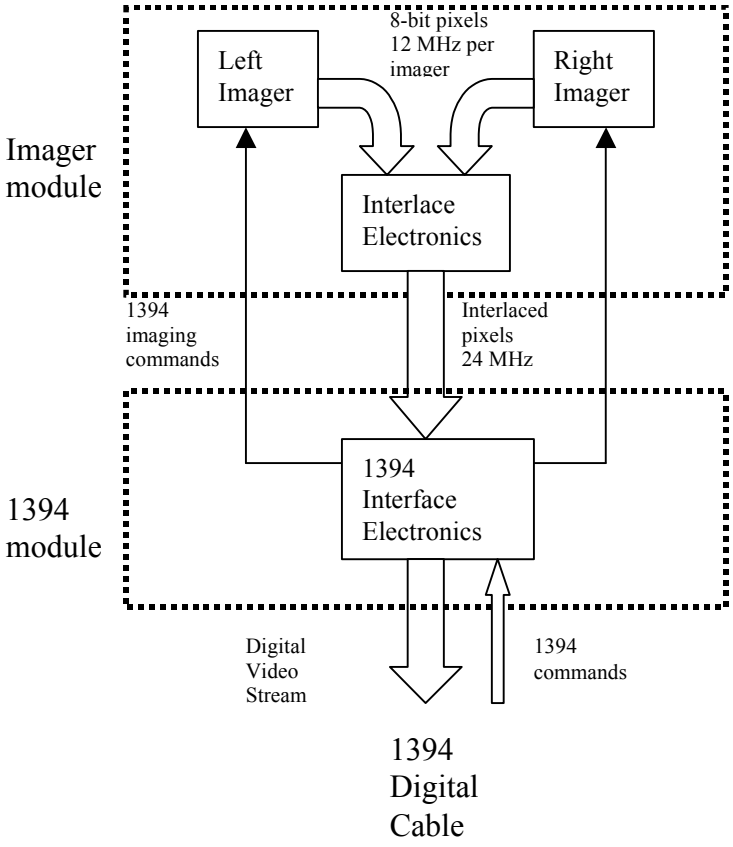


Figure 3-2 Schematic of the STH-MDCS/-C electronics.

data type, sending the left stereo image in Y, and the right image in the UV pixels.

Each image from the stereo camera has 8-bit pixels. In the case of the color version (STH-MDCS-C), the color information is encoded as a Bayer pattern in the same 8-bit pixel image.

Format	**Frame size**	**Frame rates**
Format 0, Mode 3 YUV 16 bits Left image on Y, right image on UV	640x480	3.75, 7.5, 15, 30 Hz
Format 2, Mode 0 YUV 16 bits Left image on Y, right image on UV	1280x960	3.75, 7.5

Table 1 Frame formats and sizes for the STH-MDCS/-C.

On the host computer, the SVS interface software takes the YUV stream and parses it into the left and right images, making them available as separate images in computer memory. It also performs color processing, for the STH-MDCS-C, converting the Bayer pattern into full-color RGB images.

Smaller frame sizes are also available using on-host *binning*. Binning averages neighboring pixels to produce a smaller image with improved noise characteristics. Binning available through the SVS software produces 320x240 images from 640x480 input, or 640x480 images from 1280x960 input.

4 Lenses

The STH-MDCS/-C uses standard C-mount lenses. Good-quality, fixed-focus lenses with low distortion and high light-gathering capability are best.

Lenses are characterized optically by imager size, F number, and focal length. Following subsections discuss the choice of these values.

4.1 Changing Lenses

Standard C-mount lenses have a 1" diameter, 28 threads-per-inch screw on their back end. The screw mates with the lens holder opening. To insert a lens, place it back end on the lens holder opening as straight as possible, and gently turn it clockwise (looking down at the lens) until it engages the threads of the lens holder. If you encounter a lot of resistance, you may be cross-threading the lens. Forcing it on will damage the plastic lens holder threads.

Once the threads are engaged, continue screwing it on until it seats firmly. You can snug it down, but do not tighten it excessively, since this can damage the lens and the lens holder threads.

Removing the lens is the reverse process: unscrew the lens counter-clockwise. There will be some initial resistance, and then it should unscrew smoothly.

Normal care should be used in taking care of the lenses, as with lenses for any good-quality camera.

4.2 Cleaning the Imagers

It should not be necessary to clean the imagers, since they are sealed off by an IR filter inside the lens mount.

If dirt and dust are present on the IR filter surface, they can be cleaned in the same manner as a lens. Wet a non-abrasive optic cleaning tissue with a small amount of methyl alcohol or similar lens-cleaning solvent, and wipe the imager glass surface gently. Dry with a similar tissue.

4.3 Imager Size

The *imager size* is the largest size of imager that can be covered by the lens. For the STH-MDCS, the lens must be 1/2" or greater. For some wide-angle lenses, there will be a little vignetting (darkening) on the corners of the image. Calibration and rectification of the image will usually eliminate this vignetting.

4.4 F Number

The *F number* is a measure of the light-gathering ability of a lens. The lower the F number, the better it is at pulling in light, and the better the STH-MDCS will see in low-illumination settings. For indoor work, an F number of 1.8 is acceptable, and 1.4 is even better. For outdoors, higher F numbers are fine. In any case, it is useful to have a manual iris for high light situations. While the imagers can have electronic exposure and gain control to automatically compensate for different light conditions, the acceptable illumination range can be extended by mechanical adjustment of the lens opening.

4.5 Focal Length

The *focal length* is the distance from the lens virtual viewpoint to the imager. It defines how large an angle the imager views through the lens. The focal length is a primary determinant of the performance of a stereo system. It affects two important aspects of the stereo system: how wide a field of view the system can see, and how good the range resolution of the stereo is. Unfortunately there's a tradeoff here. A wide-angle lens (short focal length) gives a great field of view, but causes a drop in range resolution. A telephoto lens (long focal length) can only see a small field of view, but gives better range resolution. So the choice of lens focal length usually involves a compromise. In typical situations, one usually chooses the focal length based on the narrowest field of view acceptable for an application, and then takes whatever range resolution comes with it.

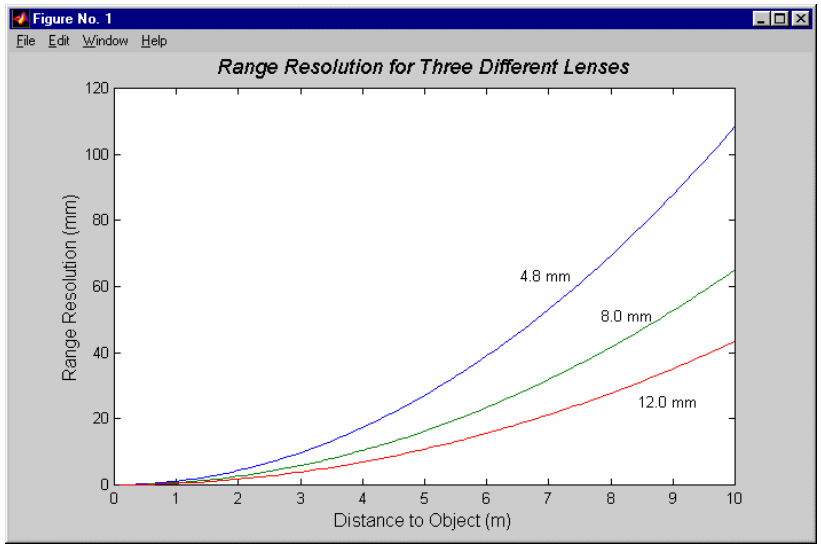


Figure 4-1 Range resolution in mm as a function of distance, for several different lens focal lengths.

4.6 Range Resolution

Range resolution is the minimum distance the stereo system can distinguish. Since stereo is a triangulation operation, the range resolution gets worse with increasing distance from the stereo head. The relationship is:

$$\Delta r = \frac{r^2}{bf}\Delta d ,$$

where b is the baseline between the imagers, f is the focal length of the lens, and Δd is the smallest disparity the stereo system can detect. For the STH-MDCS/-C, b is 90 mm, and Δd is 0.375 um (pixel size of 6.0 um, divided by the interpolation factor of 16).

Table 2 plots this relationship for several focal lengths. At any distance, the range resolution is inversely proportional to the focal length.

4.7 Field of View

The field of view is completely determined by the focal length. The formulas for the FOV in horizontal and vertical directions are:

$$HFOV = 2\arctan(3.84/f)$$

$$VFOV = 2\arctan(2.88/f)$$

where f is in millimeters. For example, a 3.5 mm lens yields a horizontal FOV of 95.3 degrees. This is about the smallest practical focal length for the STH-MDCS.

The following table shows the FOV for some standard focal lengths.

Lens focal length	Horizontal FOV	Vertical FOV
3.5 mm	95.3 deg	78.9 deg
6.0	65.2	51.3
12	35.5	27
16	27	20.4

Table 2 Horizontal and vertical field of view for different lens focal lengths.

5 1394 Interface

Digital image information is transferred from the STH-MDCS/-C to the host PC via a 1394 cable. The cable sends a video stream from the imagers to the PC, and sends commands from the PC to the stereo head to control exposure, subsampling, etc. The cable also supplies power to the stereo head.

5.1 1394 Cable

The STH-MDCS/-C must be connected to the host PC via a 6-pin male-male IEEE 1394 cable. The maximum length for such a cable is 4.5 m (about 15 feet). The cable supplies both signals and power to the stereo head. The port on the MEGA-DCS is recessed, so that it the IEEE 1394 cable plug will not stick out from the camera.

The distance between the stereo head and the PC can be extended by using a 1394 repeater.

Several 1394-enabled devices can be connected together, as long as the connection topology doesn't have any loops. The STH-MDCS/-C can be connected at any point in such a topology. At a maximum, it will need about 60% of the bandwidth of a 400 MBps connection.

5.2 1394 Host Interface

The host computer must have an available 1394 port. Some portables and desktops come with built-in ports. If these are 6-pin ports, they can be connected directly to the STH-MDCS/-C. Sony laptops also support an alternative 4-pin 1394 cabling, which has the signal pins but no power. There are adapters that convert from 4-pin to 6-pin styles; these adapters use an external power supply transformer.

If the host PC doesn't have a built-in 1394 port, one can be added by installing a 1394 PCI card or PCMCIA card for laptops. 1394 PCI cards have 6-pin ports, and supply power. PCMCIA cards do not have the capability of supplying power, and come with an adapter for supplying power to the 1394 cable through a wall transformer.

Any 1394 card is suitable, as long as it conforms to OHCI (open host controller interface) specifications. All current cards do, but some older cards may not.

6 User Controls

The CMOS imagers are fully controllable via the 1394 interface. User programs may input color images (STH-MDCS-C only), set video digitization parameters (exposure, gain, red and blue balance), and subsampling modes. All of these parameters can be set with the SRI Small Vision System. They are also accessible to user programs through the capture API (Section 8).

User controls for frame size and sampling modes are on the main capture window dialog. Video digitization controls are accessed through a dialog invoked with the *Video*... menu item. Figure 6-1 shows the dialog.

6.1 Color

Color information from the MEGA-DCS digital head (STH-MDCS-C only) is input as raw colorized pixels, and converted by the interface library into two monochrome and one or two RGB color channels. The primary color channel corresponds to the left image, which is the reference image for stereo. The right image color channel is also available. The color images can be de-warped, just like the monochrome images, to take into account lens distortion (see the Small Vision System User's Manual).

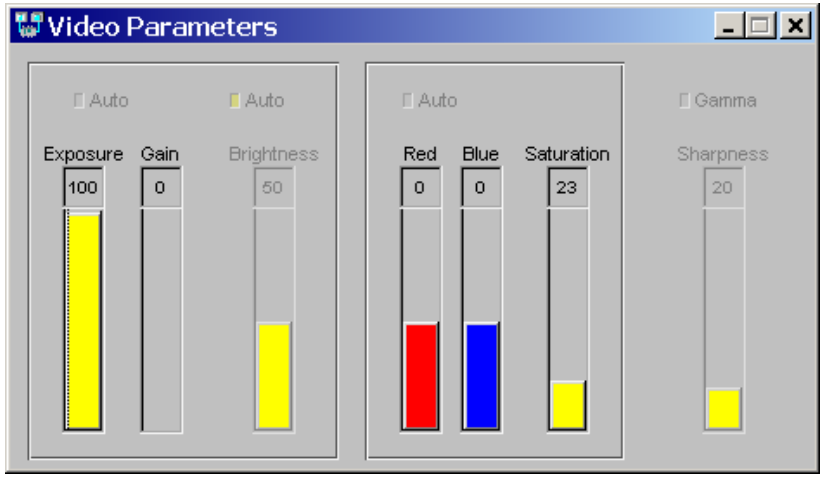


Figure 6-1 Video Parameters dialog.

Color information from the camera is input only if the `Color` button is pressed on the main window (Figure 2-1).

Because the typical color camera uses a colorizing filter on top of its pixels, the color information is sampled at a lower resolution than a similar non-colorized camera samples monochrome information. In general, a color camera has about ¼ the spatial resolution of a similar monochrome camera. To compensate for the reduced resolution, use binning (Section 6.4) to increase the fidelity of the image. For example, if you need a 320x240 frame size, use 640x480 and binning x2.

The relative amounts of the three colors, red/green/blue, affects the appearance of the color image. Many color CCD imagers have attached processors that automatically balance the offsets among these colors, to produce an image that is overall neutral (called *white balance*). The MEGA-DCS provides manual color balance by allowing variable gain on the red and blue pixels, relative to the green pixels. Manual balance is useful in many machine vision applications, because automatic white balance continuously changes the relative amount of color in the image.

The manual gain on red and blue pixels is adjusted using the *Red* and *Blue* controls on the *Video Parameters* dialog. For a particular lighting source, try adjusting the gains until a white area in the scene looks white, without any color bias.

6.2 Gamma Correction

To display properly for human viewing, most video images are formatted to have a nonlinear relationship between the intensity of light at a pixel and the value of the video signal. The nonlinear function compensates for loss of definition in low light areas. Typically the function is x^{γ}, where γ is 0.45, and the signal is called "gamma corrected." Digital cameras, such as the STH-MDCS/C, do not necessarily have gamma correction. This is not a problem for stereo processing, but does cause the display to look very dark

in low-light areas. You can add gamma correction to the displayed image by choosing an appropriate gamma value in the slider under the right display window (Figure 6-2).

6.3 Video Digitization Parameters

The CMOS imagers have electronic exposure and gain controls to compensate for varying lighting conditions. The exposure can vary from a maximum of a full frame time to a minimum of one line time. Gain is an additional amplification of the video signal, for low-light situations. It is settable from 0 to 22 dB.

Both imagers are treated in exactly the same manner. It is not possible to set a different exposure or gain on each imager.

Digitization control can operate in either manual or automatic mode. Refer to Figure 6-1 for the controls in the video capture program. Manual mode is the only currently supported mode for the STH-MDCS/C.

In manual mode, the user program sets the exposure and gain. The exposure and gain are based on a 0 to 100 scale. Here are some tips for setting exposure and gain.

- In general, keep the gain as low as possible, since it introduces additional noise into the system. Use it only if the exposure is set to maximum, or if the exposure must be kept low to minimize motion blur.
- Adjust the manual iris of the lens to as small an opening as possible for your application, without having to use gain. This will increase the depth of field and give better optical performance.

6.4 Subsampling

In many applications it is not necessary to work with the the full 1280 x 960 image. The CMOS imagers are capable of sampling the pixels in the array. Sampling allows the video stream to send less data, for faster frame rates or less bus activity. A sampled image shows the same scene as the original image, but it uses fewer pixels to do so, and has less detail. Sampling differs from *subwindowing*, which picks a rectangular portion of the image, but doesn't change its resolution.

Binning is a subsampling technique in which several adjacent pixels are averaged into one. Binning reduces video noise, sometimes quite substantially. Binning is available both on-chip and on the host PC. On-chip binning allows the STH-MCDS/-C to convert the entire 1280x960 image into a 640x480 image *before* it is sent down the IEEE 1394 bus. The binning is color-aware for the STH-MDCS-C, so that pixels of like color are combined.

Binning can also take place in the host computer, giving an additional x2 subsampling of the image. Subsampling is always done in both the vertical and horizontal direction. Subsampling x2 means that an image of size H x V will be transformed into an image of size H/2 x V/2. Subsampling x4 transforms it to an image of size H/4 x V/4.

Figure 6-2 shows the frame size and subsampling controls on the video capture application. Any x2 or x4 subsampling is allowed, including combined binning and decimation.

6.5 Frame Rates

Frame rates from the STH-MDCS/-C depend on the frame size. Table 3 shows the frame rates available for each of the frame sizes.

Binning	Frames per Second
x1 (1280 x 960)	3.75, 7.5
x2 (640 x 480)	3.75, 7.5, 15, 30
x4 (320 x 240)	3.75, 7.5, 15, 30

Table 3 Frame rates at different decimations.

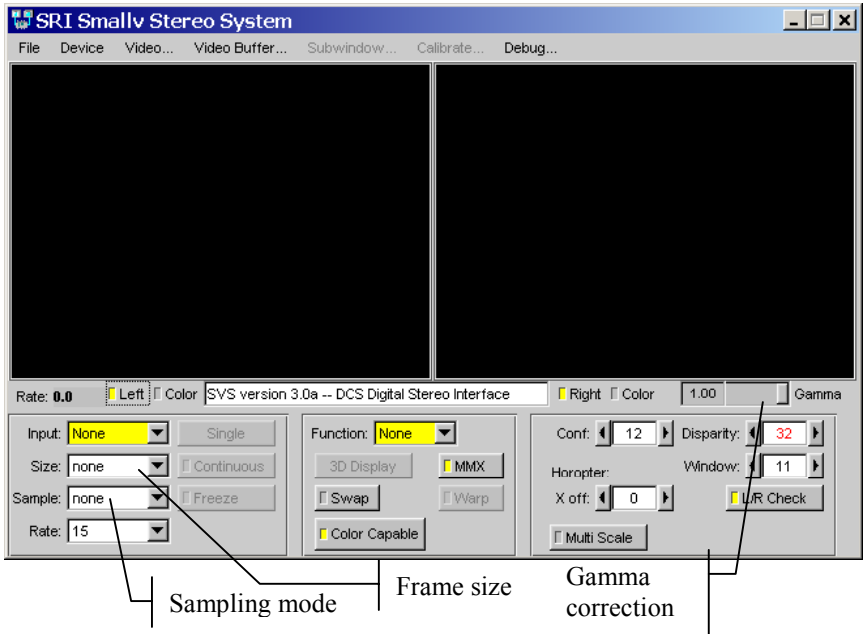


Figure 6-2 Frame size and Subsampling controls in the main capture window.

7 Installing the 1394 Host Card and Capture Software

The STH-MDCS/-C connects to a host computer via a digital 1394 interface. The host PC must have a 1394 port, and software to interface to the video stream from the camera. This interface software presents the video stream from the 1394 hardware as a set of stereo frames to the user program (see Figure 7-1). The STH-MDCS/-C comes with interface software for either MS Windows 98/2000/XP or Linux.

7.1 1394 Hardware and Drivers

Before installing the software interface, the PC must be equipped with a 1394 port. If there is one already present, on the motherboard, then you can skip this section. Otherwise you have to install a PCI or PCMCIA card. The card must be OHCI compliant, which all current cards are.

7.1.1 MS Windows Hardware Installation

MS Windows 98SE, ME, 2000, or XP is required.

For a PCI card, insert the card into a free PCI slot with the computer power off, and start the computer. With a PCMCIA card, insert it into the PCMCIA slot. In either case, the New Hardware wizard will walk you through installation steps for the low-level drivers. You may need your MS Windows 98/2000 CD to install some files.

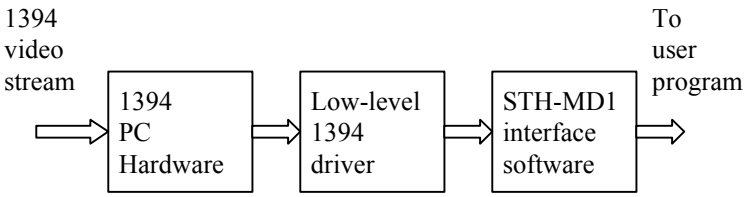


Figure 7-1 Host PC low-level software structure.

For more information about installation, please see the Videre Design website (www.videredesign.com/support_svsmsw.htm).

7.1.2 Linux Hardware and Driver Installation

Linux kernels 2.4.x are required for operation. Please see the Videre Design website (www.videredesign.com/support_svslnx.htm) for current information.

Sometimes the 1394 system will get hung and you have to unhang it by removing all the modules, and re-installing them. Also, the Linux IEEE 1394 drivers sometimes do not configure the root node of the bus properly. Check the listing of /proc/ohci1394 to see if the word "root" appears near the top of the listing. If not, you can sometimes get around this problem by using:

```
modprobe ohci1394 attempt_root=1
```

when installing the OHCI 1394 module.

7.2 STH-MDCS Software

The STH-MDCS/-C comes with the SVS stereo software, and several sample applications, including the GUI application described in this manual.

To install the software under MS Windows, execute the file `svsXXX.exe`. The installation process will add the relevant interface and application software.

To install the software under Linux, untar the file `svsXXX.tgz` in a new directory, which will become the top-level directory of the software. You should also set the environment variable SVSDIR to this directory, and add `bin/` to your LD_LIBRARY_PATH variable.

The directory structure for the software is:

```
bin/
   smallv(.exe)
   smallvcal(.exe)
```

```
      smallvmat(.exe)

      svsgrab.dll/lib
      libsvscap.so
      interface libraries
      stereo calculation libraries
   src/
      flwin.cpp
      svs.h
      flwin.h
samples/
   smallv.cpp
   fldispx.cpp
   *.dsw, *.dsp, makefile
```

There are several applications. The source code for all applications is included in the distribution. The stereo calculation libraries are also included, so that user applications can link to them. The calibration libraries are not included; the only way to run the SVS calibration procedures is through the `smallvcal(.exe)` application.

`smallv(.exe)` is a GUI-based application that allows the user to exercise the capture and stereo functions of the STH-MDCS/-C. It is described in earlier sections of this document.

`smallvmat(.exe)` is similar to `smallv`, with the addition of a MatLab interface for sending images and stereo information to MatLab. You must have installed the R13 release of MatLab to run this program.

`smallvcal(.exe)` is the same as `smallv`, with the addition of a calibration package for calibrating a stereo rig. Use this application to perform calibration on your stereo system.

`stcap(.exe)` is a simple application that connects to the stereo head and displays images. It can serve as a template for user programs that integrate stereo capture from the STH-MDCS/-C.

`stdisp(.exe)` is a simple application that connects to the stereo head, grabs images and performs stereo analysis, and displays the results. It can serve as a template for user programs that integrate stereo capture and computation from the STH-MDCS/-C.

`libsvscap.so` and `svsgrab.lib/dll` are the capture libraries for Linux and MS Windows, respectively. These libraries must be set to the correct ones for the MEGA-DCS.

In MSW Windows, execute the file `bin\setup_dcs.bat`. This will copy `svsdcs.dll/lib` as the interface libraries.

Under Linux, copy the following files in the `bin/` directory:

```
dcscap.so -> libsvscap.so  (Linux)
```

You can check that the correct interface library is installed, by looking at the information text when the capture application is started. It should say "DCS digital stereo interface". If not, the wrong interface library is installed in `svsgrab.dll` or `libsvscap.so`.

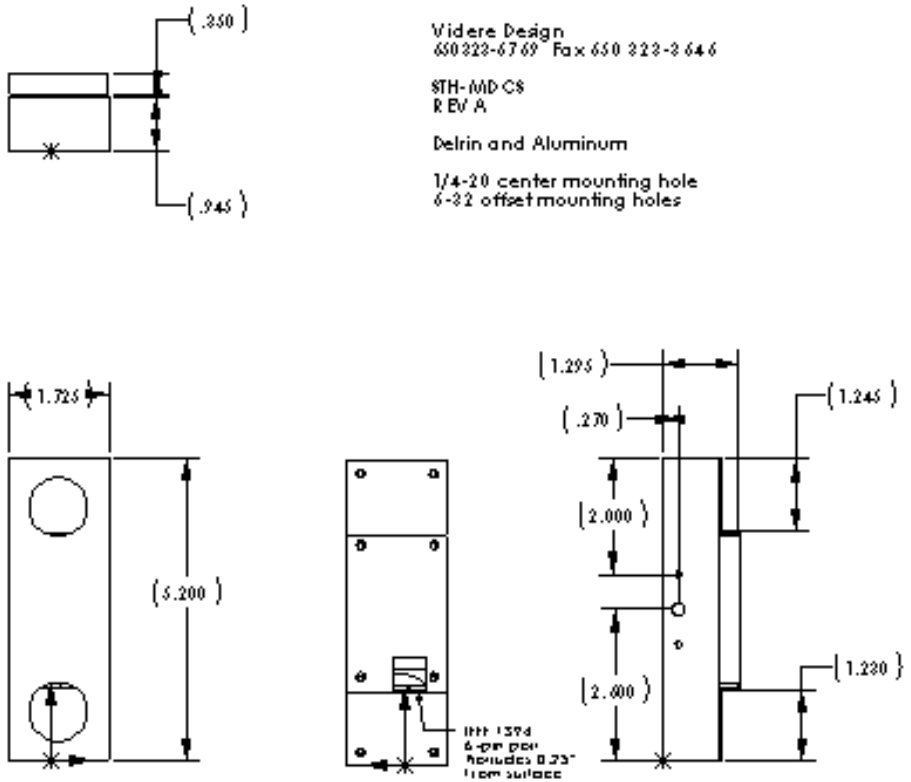
8 Interface Software API

Please see the Small Vision System manual for information about the software API for capturing and saving images.

9 Physical Dimensions and Mounting Diagram

The diagram below shows the physical dimensions for the STH-MDCS/-C.

The larger hole is threaded for a ¼-20 machine screw (standard tripod mounting screw). The two smaller holes are threaded for 6-32 machine screws.



10 Technical Specifications

Specifications

Imagers	½" format CMOS 1280x960 active area Progressive scan Color or monochrome
Digital Camera Specification	Version 1.30
Formats	1280x960, 640x480 8 bit monochrome or Bayer color pattern
Frame Rates	3.75, 7.5, 15, 30 Hz Max 7.5 Hz at 1280x960
Exposure	1 line time to full frame
Gain	0 – 22 dB
Sensitivity	2.5 V/lux-sec
S/N	> 55 dB, no gain
Power	< 1 W
Synchronization	Internal: pixel-locked External: 60 us
Lens	6.0 mm F 1.4 C mount included 3.6 mm, 8 mm, 12 mm and 16 mm lenses optional
Size	1.5" high x 5" long x 1" deep (excluding lenses)
Stereo Baseline	9 mm
SVS software	Linux kernel 2.4 MSW 98SE, ME, 2000 and XP

11 Technical Support

For technical support, please contact Videre Design by email or FAX.

Videre Design
P.O. Box 585
Menlo Park, CA 94026-0585
Fax: (650)323-3646
Email: support@videredesign.com

Technical information about stereo algorithms and stereo calibration can be found at `www.ai.sri.com/~konolige/svs`.